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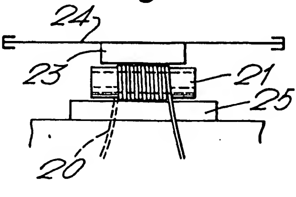
# (54) Acousto-optical fibre transducer

(57) It is known that if an optical fibre is bent sharply the microbends thus produced cause a loss of light propogated in the fibre. Further, if the fibre with microbends is moved in accordance with a parameter to be sensed, then an optical fibre sensor results.

This invention relates to a number of forms of acousto-optical sensors in which the acoustical (or vibrational) waves to be sensed are caused to move a "microbended" fibre in such a way as to modulate the light in the fibre. In a preferred version the optical fibre (20) is wound as a coil on a hollow tube (21) of oval sections. The diaphragm (24) acts on the turns of the coil via a block-like element (23), the other side of the coil being mounted on an adjustable base (25).

Fig. 7.




The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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Fig.1.

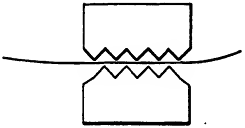


Fig.2.

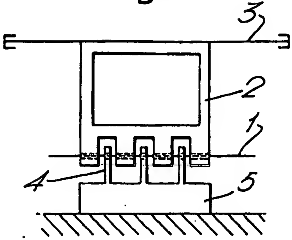



Fig.3.

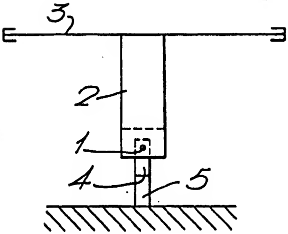



Fig.4.

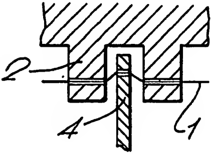



Fig.5.

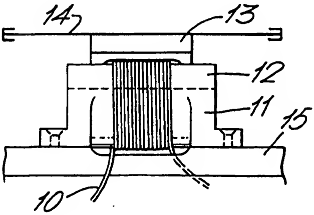



Fig.6.

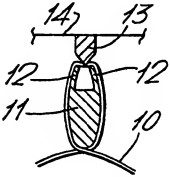


Fig. 7.

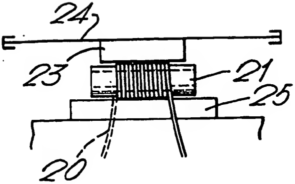



Fig. 8.

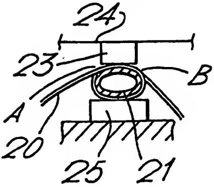



Fig. 9.

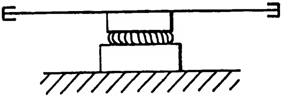


Fig. 10.

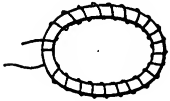


Fig. 11.

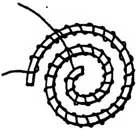
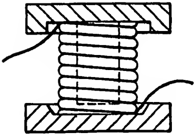


Fig. 12.



SPECIFICATION

**Optical fibre transducer**

This invention relates to acoustic-optical transducers, such as microphones, hydrophones and geophones.

It is known that when optical fibres are subjected to sharp bends, i.e. bends of small radius which are herein referred to as microbends, some of the light being conveyed by the fibre escapes therefrom. The amount of light lost in this way is approximately proportional to the inverse square of the radius over an operative range. A description of this effect, together with the application thereof as a pressure sensor, especially for very low (sub-audio) frequencies, will be found in a paper entitled "Fibre Optic Pressure Sensor" by J. N. Fields, C. K. Asawa, O. G. Ramer and M. K. Barnoski, published in the Journal of the Acoustic Society of America, Vol. 67 No. 3, March 1980, at pages 816-818.

It is an object of the invention to exploit this effect for the production of simple and economical acoustic-optical transducers.

According to the invention there is provided an acousto-optical transducer which includes at least one length of optical fibre through which light is propagated when the fibre is in use, a diaphragm or other moving element which moves in response to incident acoustical waves or vibrations, which optical fibre is maintained in tension, and means whereby the fibre is subjected to a number of microbends and the said microbends are subjected to the influence of the diaphragm or other moving element so as to modulate the light in the fibre in accordance with the incident acoustic waves or vibrations.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

*Figure 1* is an explanatory diagram indicative of a known method of producing microbends in an optical fibre.

*Figures 2, 3* and *4* are simplified diagams explanatory of the construction of a microphone which exploits the microbend effect.

*Figures 5* and *6* are simplified diagrams of another microphone using the microbend effect.

*Figures 7* and *8* are simplified diagraphs of a preferred form of microphone using the microband effect.

*Figures 9* and *10* are simplified diagrams of another form of microphone using the microbend effect.

*Figure 11* is an alternative form of multi-microband arrangement usable in the device of Figure 9.

*Figure 12* is a hydrophone or geophone in which the microbend effect is used.

In the arrangement shown in Figure 1, an optical fibre is shown being subjected by sharp bending by the action of two serrated jaws, which trap the fibre such that relative movement of the fibre subjects the fibre to a number of sharp bends. A fibre so treated is useble as a sensor in the manner described in the above-mentioned paper.

Figures 2, 3 and 4 show a microphone in which an optical fibre 1 is maintained under tension, and is threaded through alternatively-opposed holes in a frame 2 carried by a diaphragm 3 and in upstanding legs 4 on an adjustable base 5. Hence the motion of the diaphragm in respnse to sound waves causes the fibre to undulate, which modulates light passing through it. This it does because the microbends thus set up and moved cause verying amounts of light to escape from the bends. Hence the light is modulated in a manner appropriate to the incident sound. Figure 4 is an enlarged "scrap" view showing the fibre-holes arrangement. With this arrangement fibre tension may cause some difficulty.

In Figurs 5 and 6 we see an arrangement in which the fibre 10 is closely wound on a moulded former 11, which former has flexible side members 12. Thus the turns of the fibre are subjected by tension due to the action on them of a narrow blade 13 attached to the diaphragm 14. The former 11 is mounted on an adjustable base 15. Such a construction allows many portions of the fibre to be undulated in response to the incident sound waves, thus making it considerably more sensitive than the device of Figures 2, 3 and 4.

The remaining arrangements are based on the principle that the fibre is close wound on a thin walled flexible tube which may be of rubber or a plastics material. Thus the degree of radial bending can be predetermind or adjusted by the initial flattening of the tube; the fibre is always correctly tensioned whatever the degree of tube flattening used. If necessary the wound fibre can be secured to the tube by an adhesive which is also flexible.

As will be seen later, in certain cases the tube is used as a mandrel, being removed after the fibre has been suitably wound.

Figure 7 and 8, show an optical fibre 20 close-wound on a tube 21 of oval cross-section. The turns of th coil of fibres thus produced are acted on by a pressure member 23 on the diaphragm 24, and the coil rests on an adjustable base 25. To increase the number of turns of fibre which are acted on by the pressure member 23, the tube can be bent round to form a circle, or the coil can be wound on a toroid as shown in Figure 10. Figure 9 shows a microphone using such a toroidal fibre coil.

Figure 11 shows how the affective number of turns can be increased beyond that attainable with Figure 10. In this case the coil former is a spiral tube, and increasing the number of turns of the spiral increases the number of microbends.

In yet another arrangement, see Figure 12, the tube on which the fibre is wound is formed into a helix, which is also closely wound, and can be of any desired length. The diaphragm, or moving element in the case of a hydrophone or geophone can be subjected to short or long amplitude waves, dependent on whether it is being subjected to sound waves, or much greater amplitudes as could occur if the transducer is beng used to measure machinary vibrations, or as a geophone.

In all the arrangements described above, the light input is provided by an LED or a laser from which light is launched into one end of the fibre. The

resultant modulated light emanates from the other end of the fibre and falls on a photo-diode or other suitable optical receiver such as a photo-transistor.

When very high sensitivity is needed, as in microphones or hydrophones, the wall thickness of the tube element can be extremely small and the material of that tube element very soft. Alternatively, as already mentioned, the optical fibre winding may be used without a tube. For instance, it can be coated with a thin adhesive skin while held on a rod-like mandrel which is removed after the adhesive has set on the coils. The adhesive should be kept clear of the minimum radius portions A and B in Figure 8, of the tube. The fibre used can be of the cladded or uncladded type.

The arrangements described above enable simple, low cost, and robust, yet highly sensitive microphones, hydrophones and geophones to be made. Unlike other proposals for optical fibre microphones, the arrangements described above do not need gaps or breaks in the fibres.

Fluid-filled or evacuated arrangements can be used, which enables variations to be made to the relative refractive indices of the fibres and their surrounds, so that sensitivity can be varied. Fibre failure can be catered for by winding the sensitive element with two or more fibres in parallel. Such multiple winding arrangement permits overall frequency characteristics to be widened or varied by using different light wavelengths for each of the separate windings.

Miniatured microphones can also be made using the above described techniques.

## CLAIMS

1. An acousto-optical transducer which includes at least one length of optical fibre through which light is propagated when the fibre is in use, which optical fibre is maintained in tension, a diaphragm or other moving element which moves in response to incident acoustical waves or vibrations, and means whereby the fibre is subjected to a number of microbends and the said microbends are subjected to the influence of the diaphragm or other moving element so as to modulate the light in the fibre in accordance with the incident acoustic waves or vibrations.

2. A transducer as claimd in claim 1, in which the optical fibre which is in tension and is threaded through alternate holes of two sets of holes, one of which sets of holes is in a member driven by a diphragm while the other is in a stationary member.

3. A transducer as claimed in claim 1, in which the microbends are produced by wrapping the fibre about a supporting element having substantially parallel flexible wall-like portions, and in which the diaphragm carries a blade-like member which acts on the turns of the fibre in the vicinity of the wall like portions.

4. A transducer as claimed in claim 1, in which the optical fibre is wound on a tubular member of rubber or a rubber-like plastics material, and in which the diaphragm acts on the turns via a block-like member carried by the diaphragm.

5. A transducer as claimed in claim 1, in which the optical fibre is a self-supporting coil acted on by a block-like member on the diaphragm.

6. A transducer as claimed in claim 4 or 5, and in which the optical fibre coil is a circular or spiral or helical coil.

7. An acousto-optical transducer, substantially as described with reference to Figures 2 to 4, Figures 5 and 6, Figures 7 and 8, Figures 9 and 10, Figure 11 or Figure 12 of the accompanying drawings.

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